CMS L1 Calorimeter Trigger Simulation

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Introduction

- Aims
- Personnel
- Calorimeter Geometry
- Trigger algorithms

Simulation Results

- e/γ rates and efficiencies
- Jet/τ rates and efficiencies
- Trigger Rate Tables
- Efficiencies for Physics Processes
- Local production of level-1 simulation
- Summary and Conclusions

Motivation for Simulation

Optimize designs

- Identify bit count for various data paths
- verify programmable memory contents, etc.

Evaluate physics performance

- Track changing physics priorities
- Ensure high efficiency for all important physics
- Optimize use of DAQ bandwidth
- Characterize level-1 output so that higher level trigger software algorithms can be designed more efficiently

CMS Level-1 Trigger Requirements and Simulation

Capture CMS Physics with high efficiency

- **High luminosity targets:**
  - lepton/γ (40 GeV)
  - dileptons/$\gamma\gamma$ (20 GeV)
  - jets w/ missing E_T (100 GeV)
  - 1-4 jets (250-100 GeV)
- **Low Luminosity Targets:**
  - lepton/γ (25 GeV)
  - dileptons/$\gamma\gamma$ (15 GeV)
  - jets w/missing E_T (50 GeV)
  - 1-4 jets (150-75 GeV)

Capture CMS Physics with low background rate

- **75 kHz design output x 33% safety factor x 50% into muon & calorimeter triggers = 12 kHz target for simulated rates each**
  - Safety factor for unknown physics, detector modelling & DAQ performance
  - Demonstration required using basic trigger capability (not all features)

Full Simulation of Detector, Electronics & Trigger

- **ORCA4 -- Object-Oriented Reconstruction for CMS Analysis:**
  - Complete Detector GEANT modeling
  - Complete digital hit reconstruction
  - Accurate bit-level integer simulation of trigger function

CMS Level-1 Calorimeter Trigger in ORCA4

ORCA: *Object-oriented Reconstruction for CMS Analysis*

- **Considerable effort was made to implement CMS Level-1 Regional Calorimeter Trigger systems into OO code**
  - Complete detector and electronics modelling
- **Effort continues to maintain/update existing L1 Calorimeter Trigger code**
  - Level-1 Calorimeter Trigger developed and maintained by UW (Dasu, Chumney, di Lodovico, Mulvihill)
- **Collaboration wide studies of trigger effects and exploration of physics channels**
- **Large database exists of QCD events and physics channels**
  - nearly 600000 QCD events
  - physics channels added regularly
    - **Standard model: $H\rightarrow\gamma\gamma$, $H\rightarrow bb$, $W\rightarrow e\nu$, $Z\rightarrow ee$, top quark, $H\rightarrow ZZ$**
    - **SUSY higgs: $H\rightarrow\tau\tau$, $H^+\rightarrow\tau\nu$**
    - **mSUGRA: sparticles**

People working on Simulation Tasks

Faculty: *S. Dasu, W. Smith*

Scientists: *P. Chumney (DOE), F. di Lodovico (UW)*

Students: *D. Mulvihill (Undergrad. DOE), R. Rajamani (Grad. UW CS)*

Computing: *S. Rader (UW System Manager)*

Simulation Production

- Condor (*Mulvihill, Rajamani*)
- Physics (*Chumney, Dasu, di Lodovico*)

L1 Analysis *(Chumney, Dasu, di Lodovico)*

- Rates
- Efficiencies

L2 Analysis *(di Lodovico)*

- Characterize L1 output
- Development of algorithms
- Refinement of algorithms

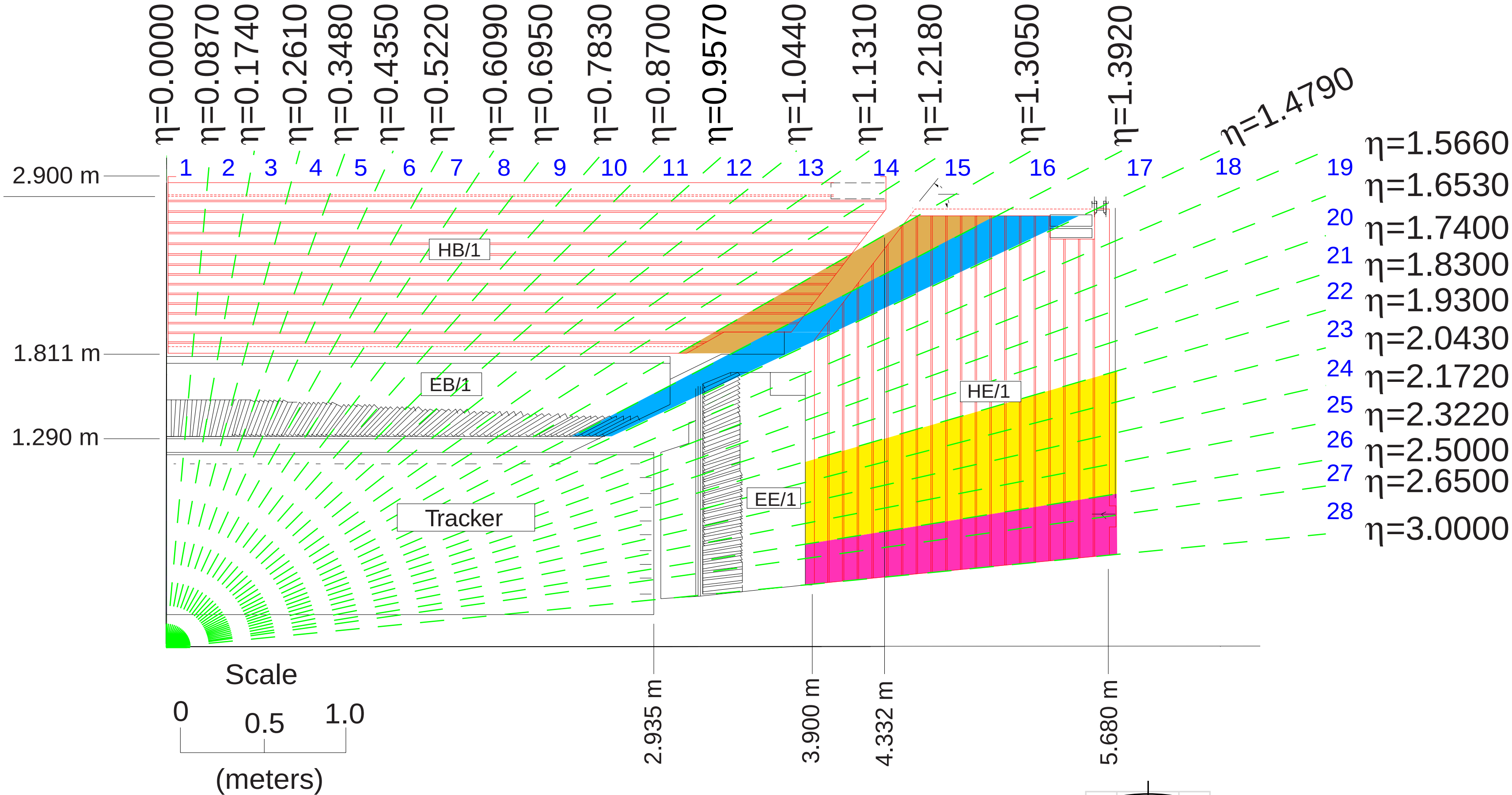
Level-1 MC Production

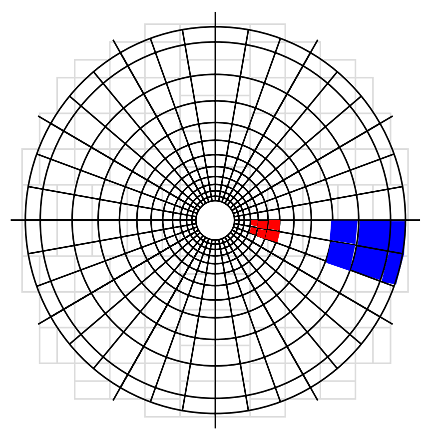
Using UW Condor system (see http://www.cs.wisc.edu/condor/)

- funded by UW
- S. Rader - system manager, R. Rajamani - production coord.
- submitted from local machine → sees local disks
- 1.2 TB RAID for storage
- 20 local CPUs - 5 are Objectivity servers
- Additional 600+ CPUs accessible in Condor pool
- Beginning to assist with Spring 2001 CMS MC Production
- Have created own level-1 datasets (& own minbias):
  - have samples for $t \rightarrow eX$, $Z^0 \rightarrow ee$, $W^\pm \rightarrow e\nu$
  - want to add $t \rightarrow$jets and more...

Actively collaborating with other US production sites, with FNAL as coordinating site.

Calorimeter Trigger Geometry



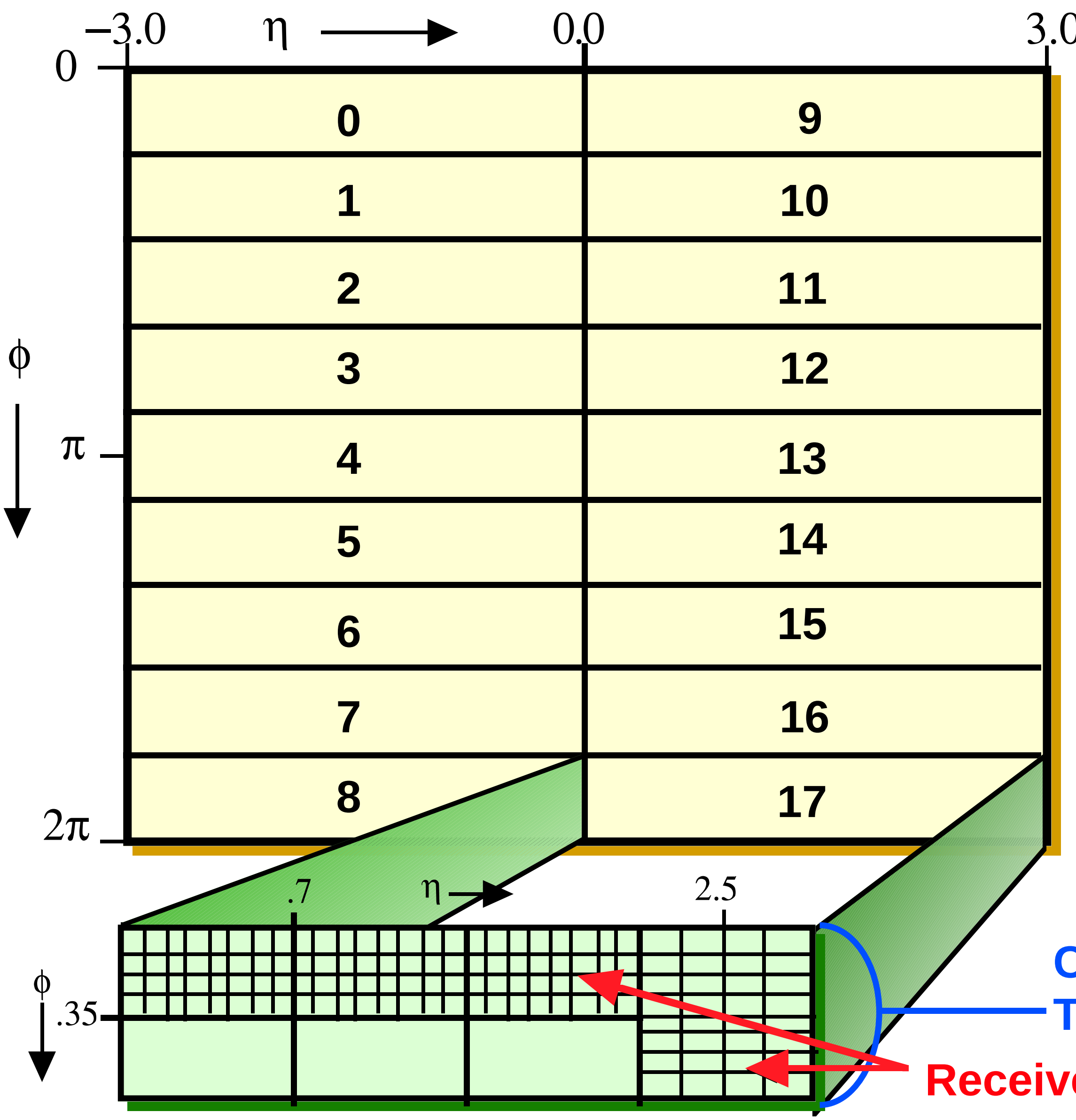


2 CMS HF Calorimeters mapping onto Trigger System HF Crate

Readout segmentation: 36ϕ × 12η × 2z × 2F/B

Trigger Tower segmentation: 18ϕ × 4η × 2F/B

Cal. Trigger Tower Mapping



18 crates for barrel & endcap calorimeters + 1 for v. forward.

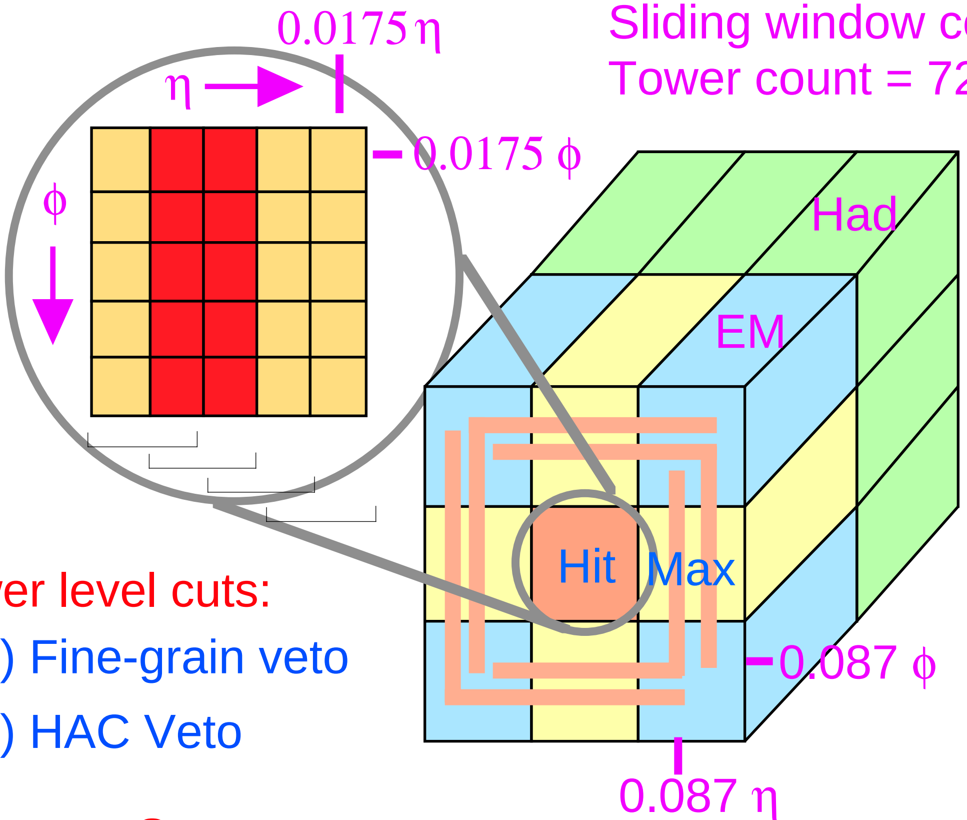
Each crate processes a 0.7 φ x 3.0 η region.

Each Receiver/Elec. ID card pair typically covers a .35 φ x 0.7 η region (modified in high-η endcap region)

Calorimeter Regional Trigger Crate

Receiver Cards (x7/crate)

Electron/Photon Algorithm



Sliding window covering all η–φ plane
Tower count = 72φ x 56η x 2 = 8064

Candidate Energy:

Max: Max E_t of 4 Neighbors

Hit: Hit + Max E_t > Threshold

Tower level cuts:

1) Fine-grain veto
2) HAC Veto

Isolation Cuts:

3) Neighbor FG/HAC Veto
4) Neighbor EM E_t Veto

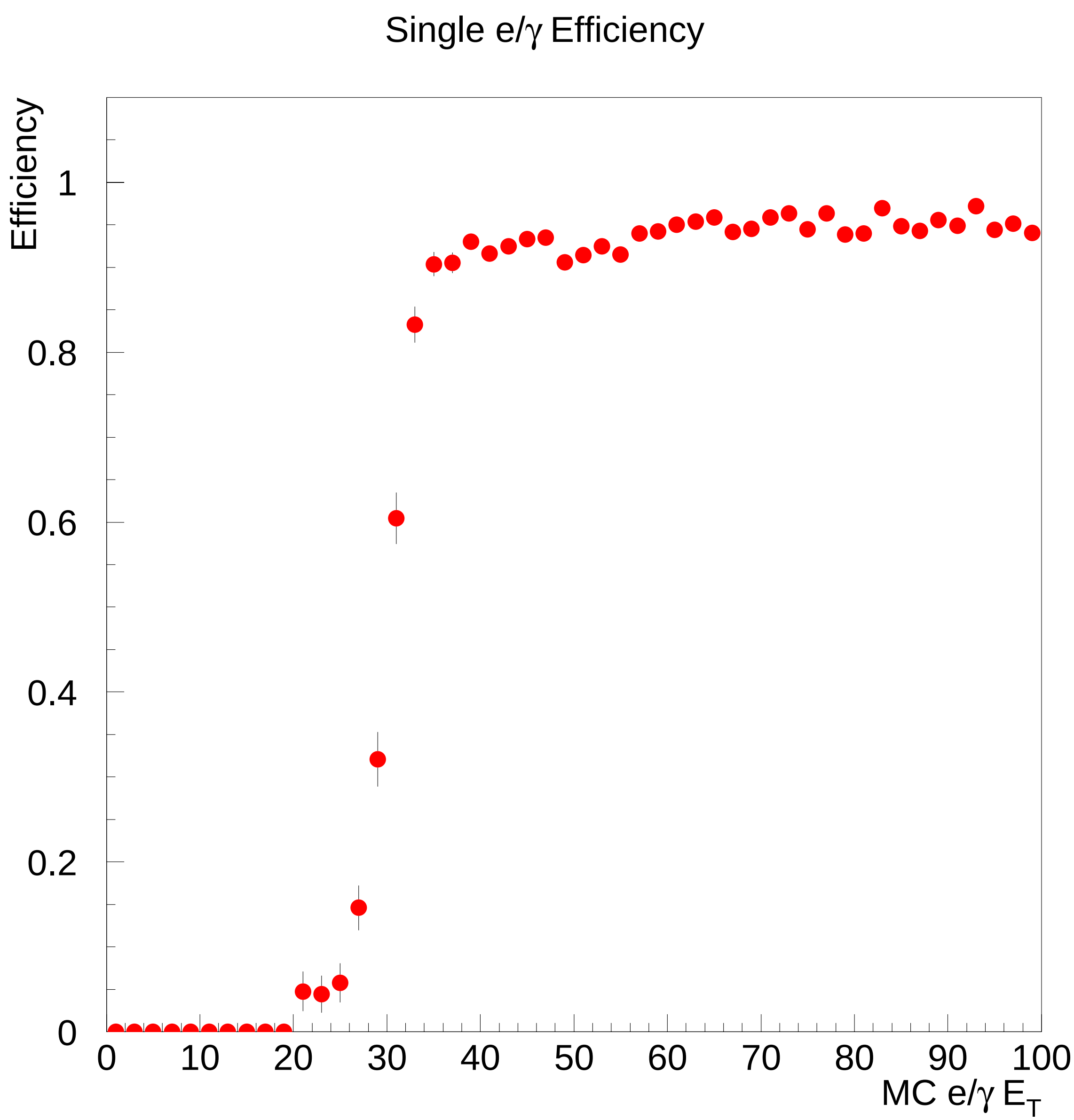
Summary:

Sort over all (η,φ) plane to find top-4 isolated and non-isolated candidates separately.

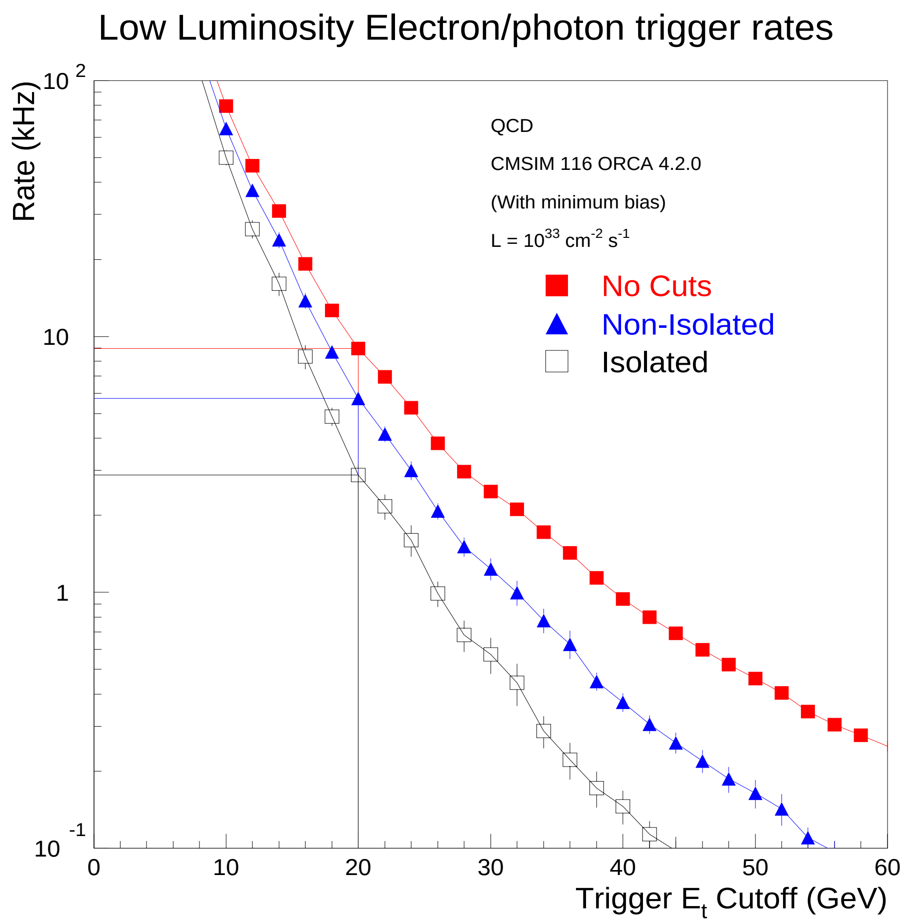
e/γ Efficiency

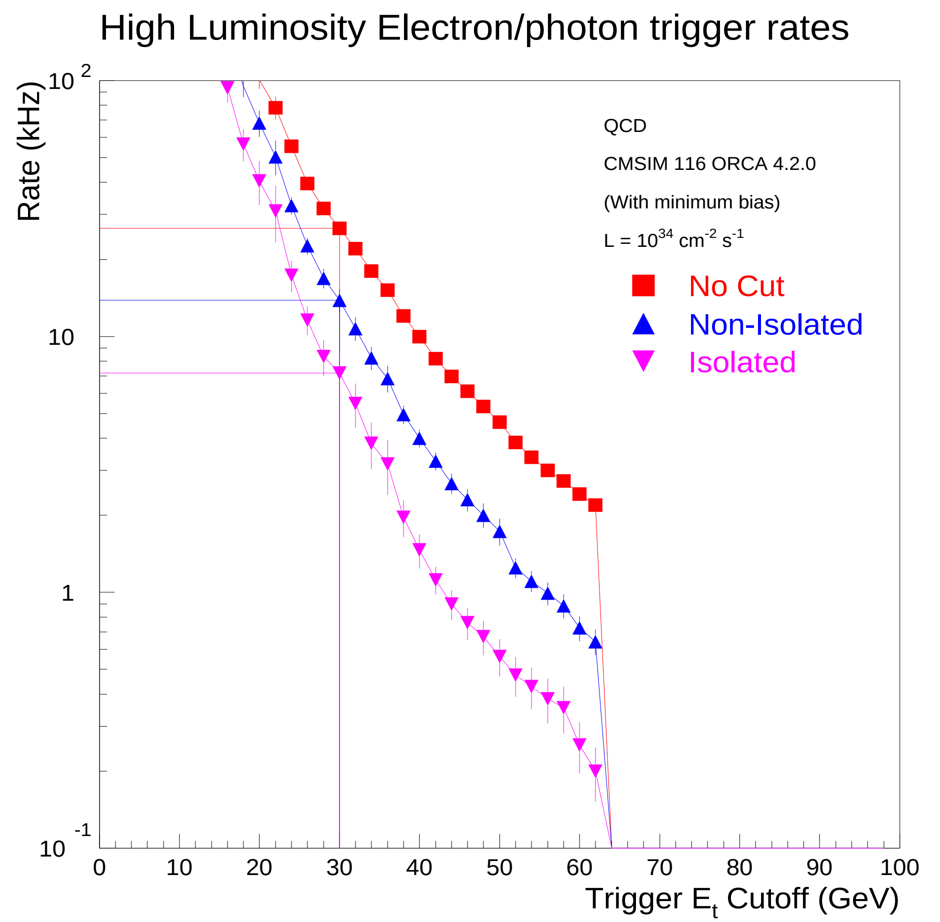
Details

- Electrons/Photons from higgs decay events with high luminosity (10^{34} cm^{-2} s^{-1}) in-time and out-of-time pileup
- 95% efficiency threshold of 35 GeV



Single e/γ Rates



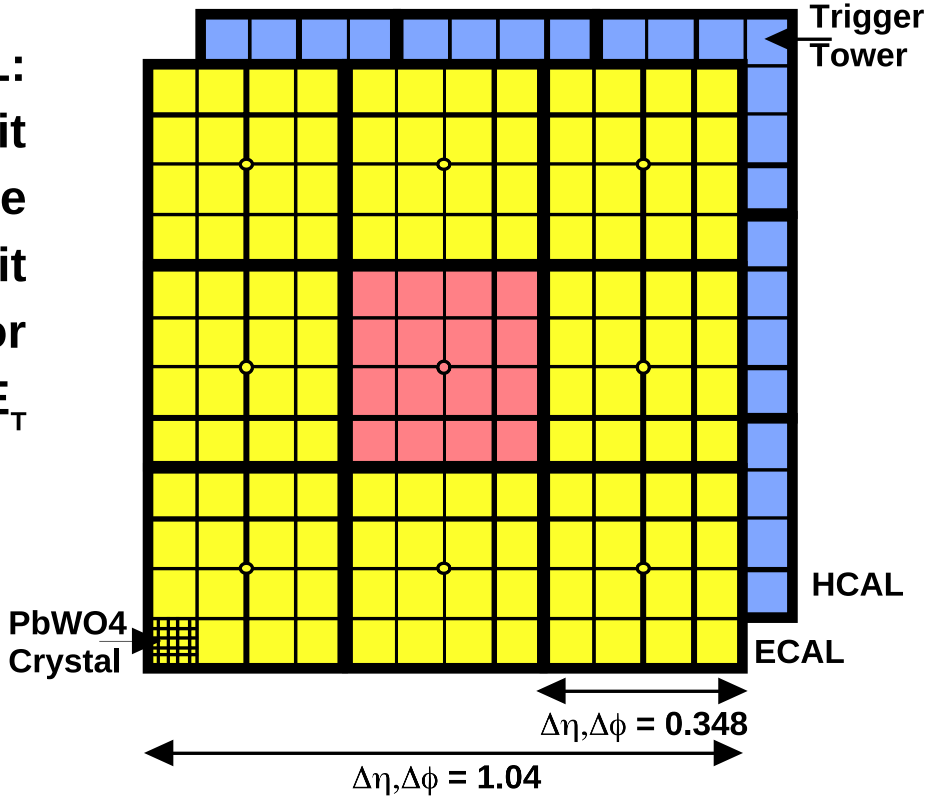


Low ℒ Trigger: Non-isolated electrons
Isolation not needed to control rate.
95% efficiency threshold at 24 GeV
Rate 6 of kHz

High ℒ Trigger: Isolated electrons
95% efficiency threshold at 35 GeV
Rate of 7 kHz

Jet Algorithm

Input from E/HCAL: Programmable 8-bit nonlinear scale converted to 10-bit linear scale for sums to obtain jet E_T



Active towers counted after a trigger tower level programmable threshold. τ-veto bit formed by requiring that there be no more than 2 active ECAL or HCAL towers in a 4x4 region

Jet or τ E_T

- 12x12 trigger tower E_T sums in 4x4 region steps with central region > others

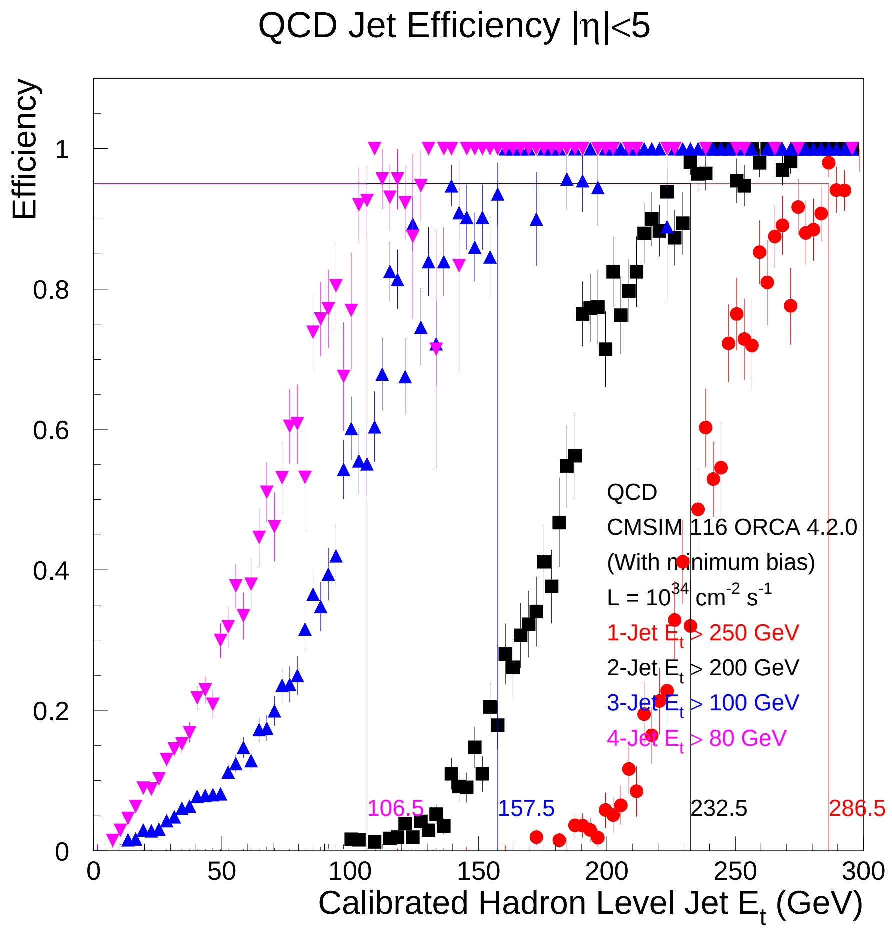
τ algorithm

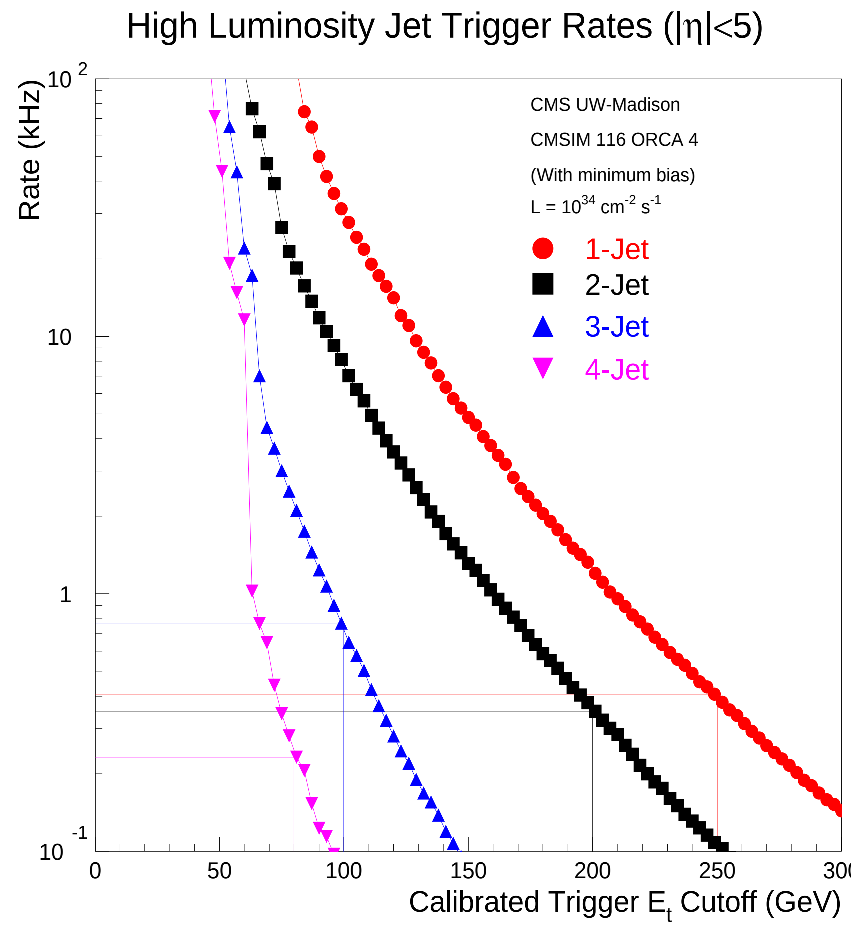
- redefine jet as τ-jet if none of the nine 4x4 region τ-veto bits are on

Output

- top 4 τ-jets and top 4 jets in central rapidity, and top four jets in forward rapidity

Jet Efficiency and Rates

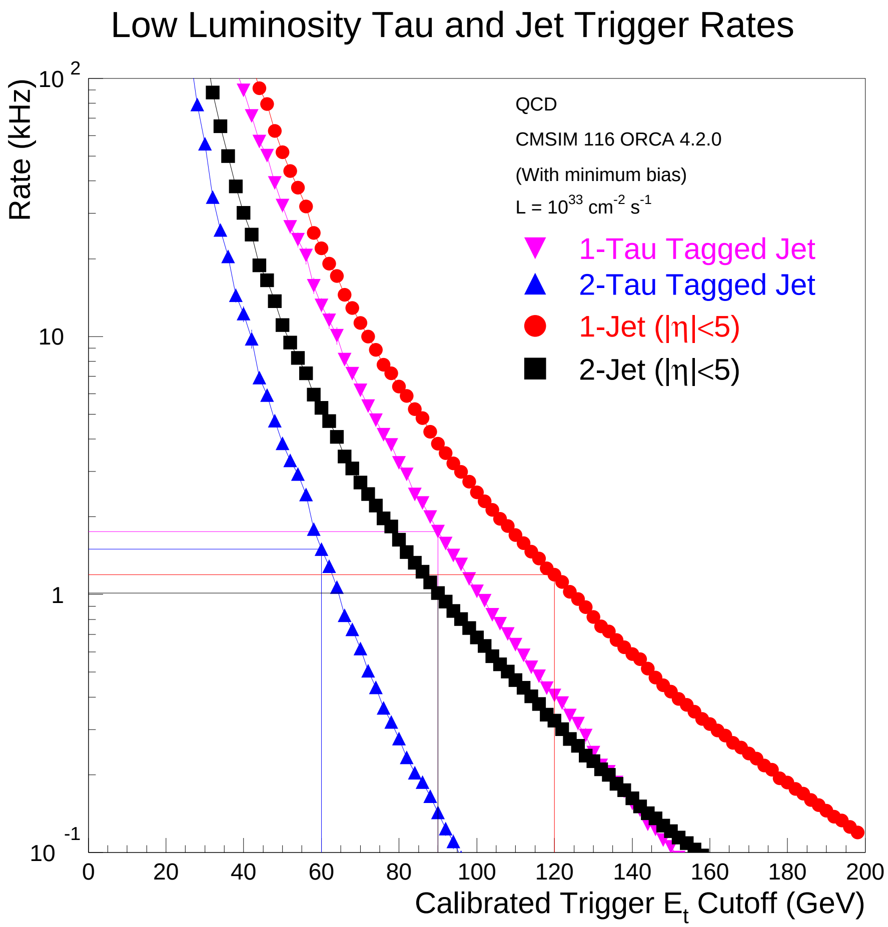


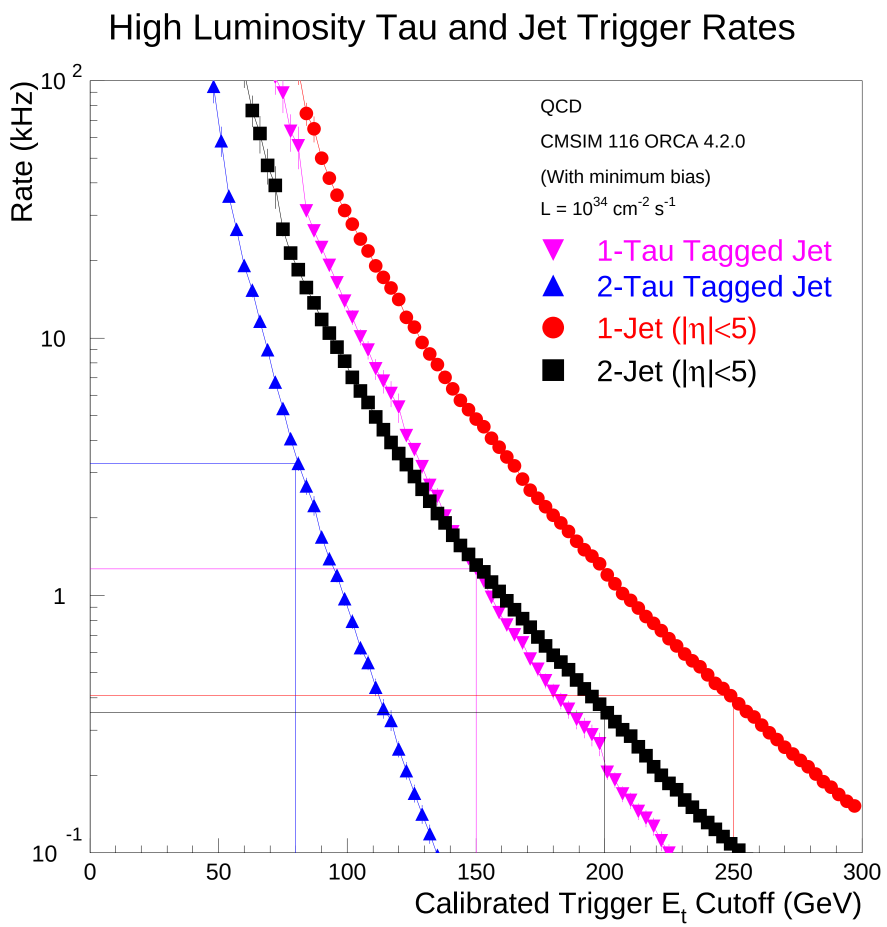


10^{34} cm^{-2} s^{-1} with in-time and out-of-time Pileup.
Both vs. calibrated energy and jets to |η|<5.

	1-jet	2-jet	3-jet	4-jet
95% eff. Threshold	285 GeV	225 GeV	125 GeV	105 GeV
Rate	0.4 kHz	0.4 kHz	0.7 kHz	0.2 kHz

Jet/τ Rate Comparison





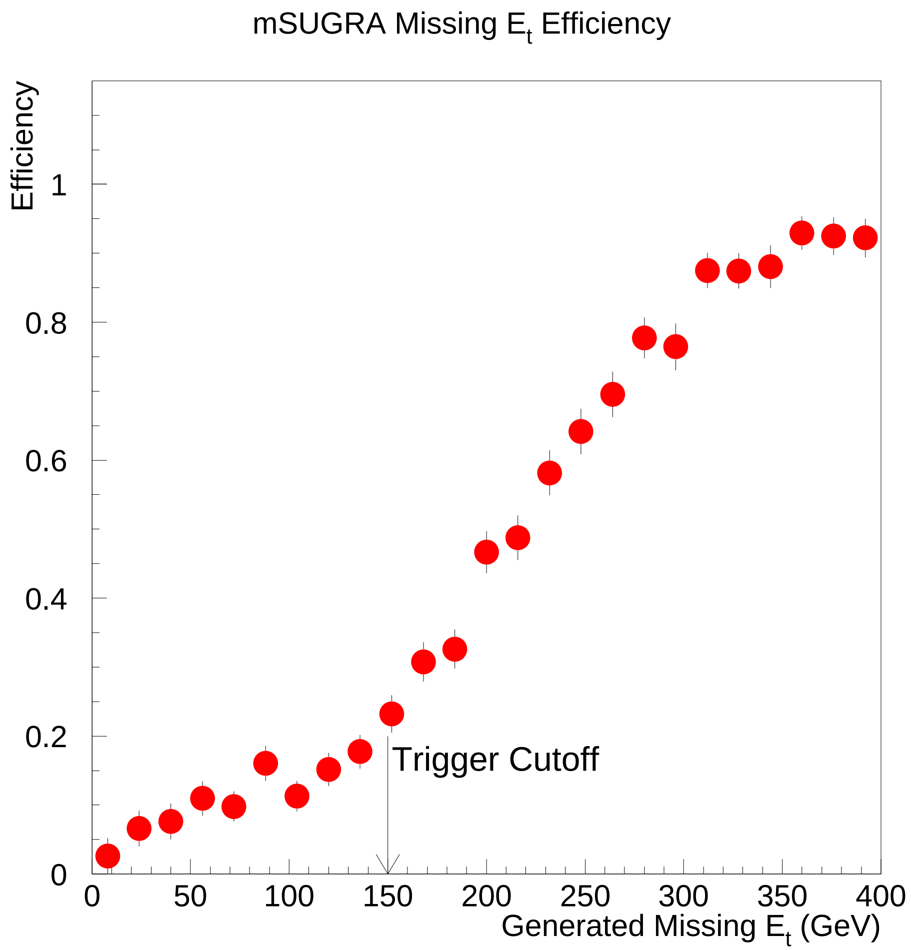
Tau-Tagged Jets only to |η|<2.5 (tracker acceptance)

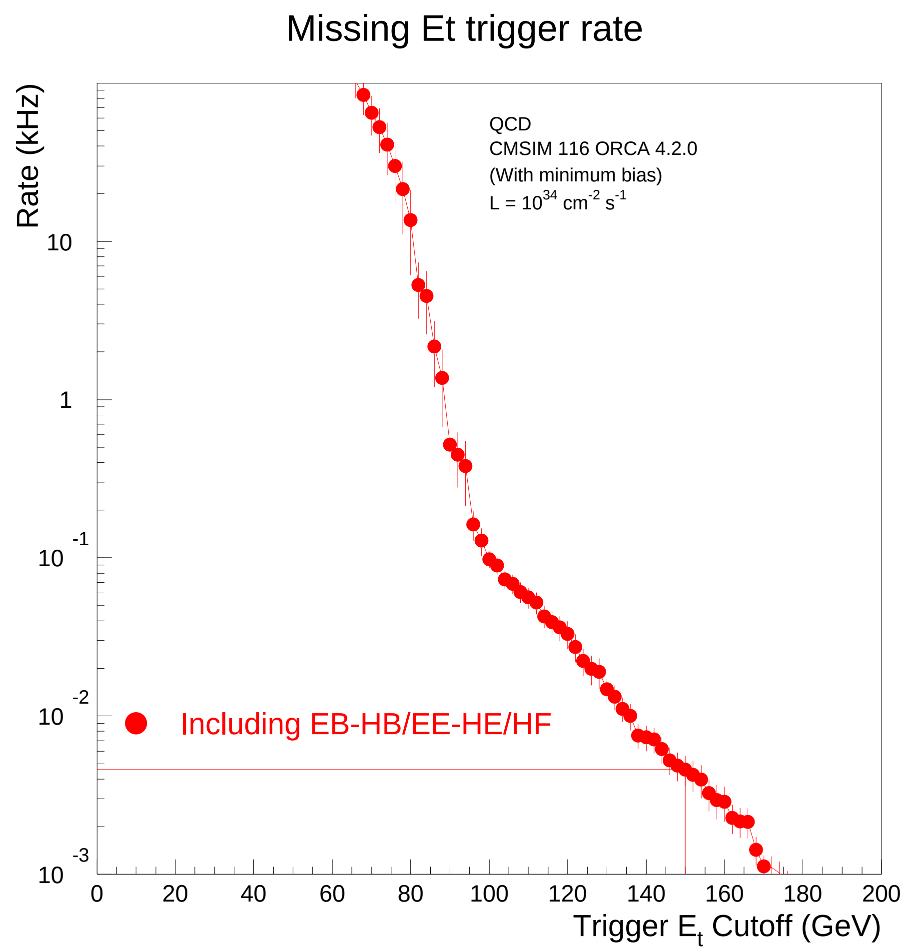
Jet energy corrections applied throughout.

Jets are any type of jet, regardless of tag, to |η|<5.

	Low $\mathscr{L}$	High $\mathscr{L}$
1 τ-jet 95% Thr.	95 GeV	180 GeV
2 τ-jet 95% Thr.	75 GeV	110 GeV
H→ττ eff.	96%	73 %

Missing E_T Efficiency and Rate





mSUGRA events
Cutoff at 150 GeV
Coverage to |η|<5

Steep slope in new rate is where pileup is "dying out".

Improved calibration will reduce the pileup's effect on missing E_T.

L1 Trigger Thresholds with ORCA4 simulated rate

	e	ee	τ	ττ	j	jj	jjj	jjjj
Low $\mathcal{L}$	24	18	95	75	150	115	95	75
High $\mathcal{L}$	35	20	180	110	285	225	125	105
	τ+e	j+e	MET	e+MET	j+MET	e(NI)	ee(NI)	ΣET
Low $\mathcal{L}$	80,14	125,14	275	12,175	65,175	NA*	NA*	1000
High $\mathcal{L}$	125,20	165,20	350	18,250	95,250	58	28	1500
	μ	μμ	μe	μτ	μj	μ+ET	μ+MET	Rate:
Low $\mathcal{L}$	10	3	4,12	4,80	4,80	4,600	4,140	25 kHz
High $\mathcal{L}$	25	8,5	5,32	5,140	5,155	5,800	5,200	25 kHz

75 kHz x 33% safety factor = 25 kHz target for simulated rates

Threshold is defined as either 95% (e/γ, τ, j) & 90% (MET, μ) efficiency and is calibrated to uniformly match off-line energy.

*Isolation not used for electron triggers at low luminosity

ET=Total E_T, MET = Missing E_T, NI = Non Isolated

Trigger Physics Efficiencies
Corresponding to 12 kHz ORCA4 simulated rate

Channel	Low $\mathcal{L}$	High $\mathcal{L}$	Triggers Used
H(200) $\rightarrow \tau\tau \rightarrow$ hadrons	93%	60%	e1, τ1, j1, e2, τ2, j2
H(500) $\rightarrow \tau\tau \rightarrow$ hadrons	99%	86%	e1, τ1, j1, e2, τ2, j2
H(170) $\rightarrow$ 4 electrons	100%	99%	e1, e2
H(110) $\rightarrow$ 2 photons	99%	98%	e1, e2
H(135) $\rightarrow \tau\tau \rightarrow$ e, hadron	96%	72%	e1, e2, τ1, j1
H(200) $\rightarrow \tau\tau \rightarrow$ e, hadron	96%	74%	e1, e2, τ1, j1
H(120) $\rightarrow$ Invisible (tag jets)	96%	58%	j1, j2, missing ET
H(120) $\rightarrow$ ZZ* $\rightarrow$ e, e, μ, μ		73%	e1, e2
H(200) $\rightarrow$ ZZ $\rightarrow$ e, e, jets		95%	e1, e2, j1, j2
tt $\rightarrow$ e, X	97%	82%	e1, j1, j2, j3, j4
tt $\rightarrow$ e, H+, X1 $\rightarrow$ e, τ, X2	94%	76%	e1, j1, j2, j3, j4

Note: e at low $\mathcal{L}$ does not require isolation

Post TDR Physics Trigger Efficiencies

Channel	Low $\mathcal{L}$	High $\mathcal{L}$	Triggers Used	Comments
$tt \to eX$*		66%	e1	Additional gain from jet trigger
$Z \to ee$		90%	e1 e2	e1: 77% e2: 72%
$W \to e\nu$		47%	e1 e2	Neutrino too soft to help trigger
$H+ \to \tau$ + Missing ET + jjj		57%	t1 t2	jet,electron triggers also can contribute
mSUGRA		80%	j1 j2 j3 j4	soft narrow jets in τ trigger, 68% τ only
$H(110) \to bb$	83%	40%	j1 j2 j3 j4 t1 t2	High lumi is hard to analyze
$H(130) \to bb$	84%	40%	j1 j2 j3 j4 t1 t2	May improve with $\Delta\eta$ cut between two jets

Efficiencies use all triggers except muon triggers

Included in total 12 kHz ORCA4 simulated L1 Calorimter Trigge rate

FNAL and Wisconsin Simulation

Analysis by P.Chumney and F. di Lodovico

Conclusions

Regional Calorimeter Trigger Simulation Captures CMS Physics

- **High efficiency and low background**
- **Demonstrated by detailed realistic simulation**
- **Wide variety of signals studied**
  - Published in December: CMS NOTE 2000/074: "CMS Level-1 Regional Calorimeter Trigger Simulation Results"
- **Work continues on new LHC physics of interest, modifications and improvements to detector, results from Higher Level Trigger**
- **UW/FNAL simulation production effort part of collaboration wide effort**
- **New simulation production effort will be used to verify rates, check efficiencies, etc.**